Lect.12

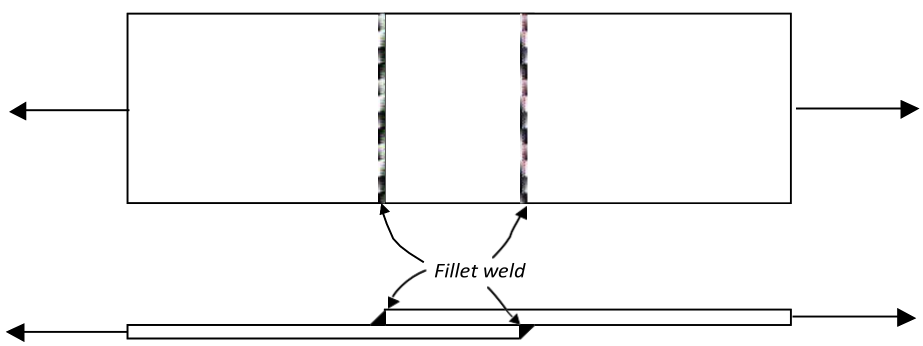
WELDED CONNECTIONS

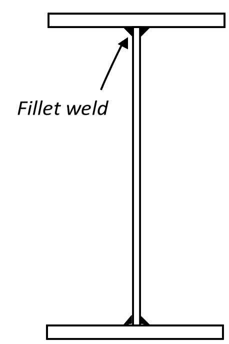
Introduction:

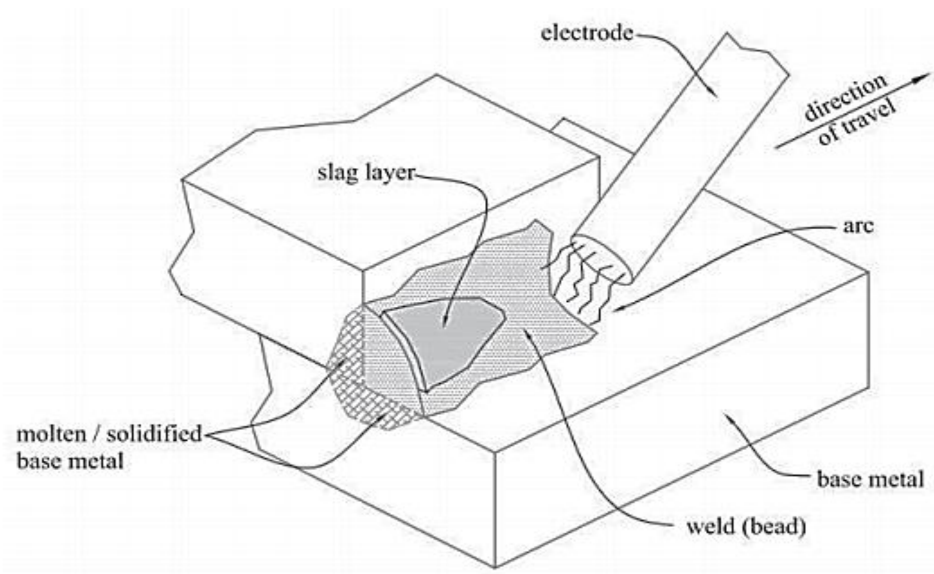
Welding is a process in which two steel members are heated and fused together with or without the use of filler metal. In structural steel buildings, connections often incorporate both welds and bolts. The use of bolts or welds in any connection is a function of many factors, such as cost, construction sequence, constructability, and the contractor's preference. Welded connections offer some advantages over bolted connections, although they do have some disadvantages.

Concepts:

- Structural welding is a process by which the parts that are to be connected are heated and fused, with supplementary molten metal at the joint.
- A relatively small depth of material will become molten, and upon cooling, the structural steel and weld metal will act as one continuous part where they are joined.







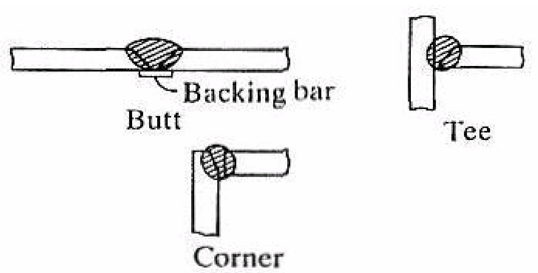
- The additional metal is deposited from a special electrode, which is part of the electric circuit that includes the connected part.
  - In the **shielded metal arc welding (SMAW)** process, *current* arcs across a gap between the electrode and the base metal, heating the connected parts and depositing part of the electrode into the molten base metal.
  - A special coating on the electrode vaporizes and forms a protective gaseous shield, preventing the molten weld metal from oxidizing before it solidifies.
  - The electrode is moved across the joint, and a weld bead is deposited, its size depending on the rate of travel of the electrode.
  - As the weld cools, impurities rise to the surface, forming a coating called *slag* that must be removed before the member is painted or another pass is made with the electrode.
  - Shielded metal arc welding is usually done manually and is the process universally used for field welds.
- For shop welding, an automatic or semi-automatic process is usually used. Foremost among these is the submerged arc welding (SAW),
- In this process, the end of the electrode and the arc are submerged in a granular flux that melts and forms a gaseous shield. There is more penetration into the base metal than with shielded metal arc welding, and higher strength results.
- Other commonly used processes for shop welding are *gas shielded metal arc, flux cored arc*, and *electro-slag welding*.
- Quality control of welded connections is particularly difficult, because defects below the surface, or even minor flaws at the surface, will escape visual detection. Welders must be

properly certified, and for critical work, special inspection techniques such as radiography or ultrasonic testing must be used.

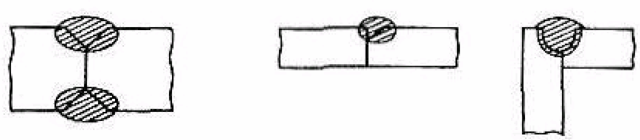
- The two most common types of welds are the fillet weld and the groove weld. Fillet weld examples: lap joint – fillet welds placed in the corner formed by two plates

Tee joint – fillet welds placed at the intersection of two plates.

- Groove welds – deposited in a gap or groove between two parts to be connected e.g., butt, tee, and corner joints with beveled (prepared) edges
- Partial penetration groove welds can be made from one or both sides with or without edge preparation.



(a) Complete Penetration Groove Welds

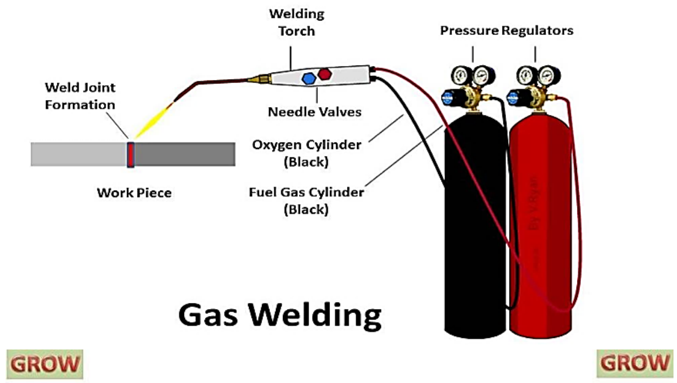

(b) Partial Penetration Groove Welds

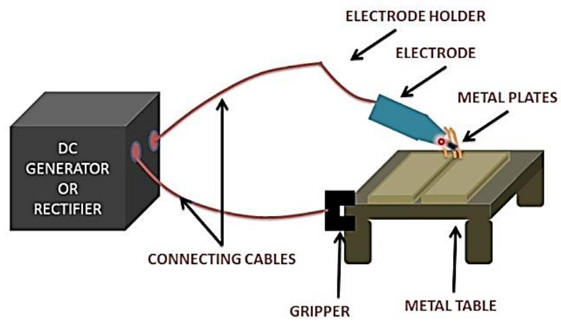
Advantage of welding

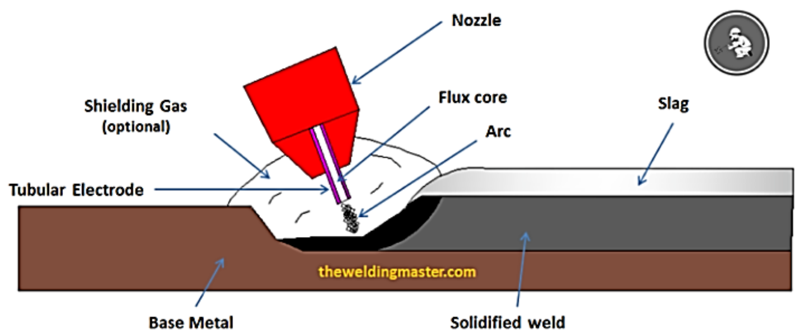
1. Welding has a much wider range of application than bolting.
2. Economics.
3. Eliminate punching and drilling of holes.
4. Welding structures are more rigid.
5. No noisy in work.
6. Fewer pieces are used as a result of saving weight & time.

Type of welding process:

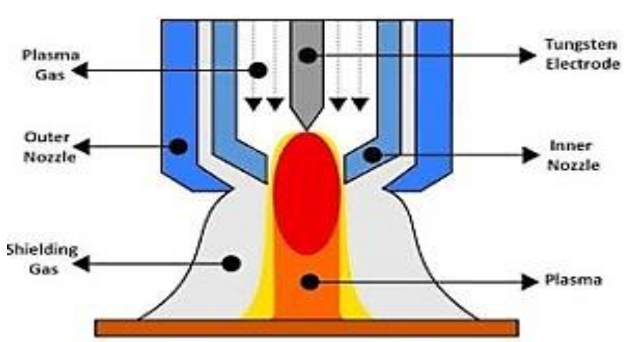
1. Gas welding.
2. Electrical welding.
3. Flux arc welding.
4. Plasma Welding and Cutting.







Flux Cored Arc Welding (FCAW)



Principle of Plasma Arc Welding

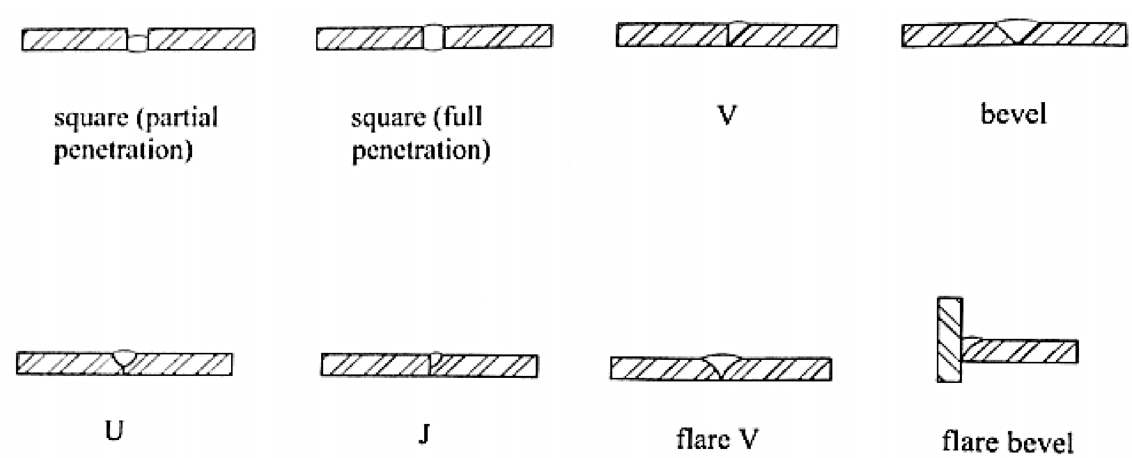
Abbreviation

- **AWS: American welding society.**
- **SMAW: Shielded metal arc welding.**
- **AWD: Arc welding design.**
- **FCAW: Flux Cored Arc welding.**
- **GTAW: Gas tungsten arc welding**

TYPES OF WELD:

Main types are fillet weld , groove weld and Butt weld.
Secondary types are plug and slot weld.

Groove Welds



1a. Effective Area

Tables J2.1 and J2.2 show that the effective throat of partial-joint-penetration **(PJP)** and flare groove welds is dependent upon the weld process and the position of the weld.
It is recommended that the design drawings should show either the required strength or the required effective throat size and allow the fabricator to select the process and determine the position required meeting the specified requirements. Effective throats larger than those in Table J2.2 can be qualified by tests. Weld reinforcement is not used in determining the effective throat of a groove weld but reinforcing fillets on T and corner joints are accounted for in the effective throat. See AWS D1.1/D1.1M Annex A(AWS, 2010).

1b. Limitations

Table J2.3 gives the minimum effective throat thickness of a PJP groove weld. Notice that for PJP groove welds Table J2.3 goes up to a plate thickness of over 6 in. (150 mm) and a minimum weld throat of 5/8 in. (16 mm), whereas for fillet welds Table J2.4 goes up to a plate thickness of over ¾ in. (19 mm) and a minimum leg size of fillet weld of only 5/16 in. (8 mm). The additional thickness for PJP groove welds is intended to provide for reasonable proportionality between weld and material thickness. The use of single-sided PJP groove welds in joints subject to rotation about the toe of the weld is discouraged.

Fillet Welds

2a. Effective Area

The effective throat of a fillet weld does not include the weld reinforcement, nor any penetration beyond the weld root. Some welding procedures produce a consistent penetration beyond the root of the weld. This penetration contributes to the strength of the weld. However, it is necessary to demonstrate that the weld procedure to be used produces this increased penetration. In practice, this can be done initially by cross-sectioning the runoff plates of the joint. Once this is done, no further testing is required, as long as the welding procedure is not changed.

2b. Limitations

Table J2.4 provides the minimum size ofa fillet weld for a given thickness of the thinner part joined. The requirements are not based on strength considerations, but on the quench effect of thick material on small welds. Very rapid cooling of weld metal may result in a loss of ductility. Furthermore, the restraint to weld metal shrinkage provided by thick material may result in weld cracking.

The use of the thinner part to determine the minimum size weld is based on the prevalence of the use of filler metal considered to be "low hydrogen." Because a 5/16-in. (8 mm) fillet weld is the largest that can be deposited in a single pass by the SMAW process and still be considered prequalified under AWS D1.1/D1.1M, 5/16 in. (8 mm) applies to all material greater than 3/4 in. (19 mm) in thickness, but minimum preheat and interphases temperatures are required by AWS D1.1/D1.1M.The design drawings should reflect these minimum sizes, and the production welds should be of these minimum sizes. For thicker members in lap joints, it is possible for the welder to melt away the upper corner, resulting in a weld that appears to be full size but actually lacks the required weld throat dimension. See Figure C-J2.1(a).On thinner members, the full weld throat is likely to be achieved, even if the edge is melted away. Accordingly, when the plate is ¼ in. (6 mm) or thicker, the maximum fillet weld size is 1/16 in. (2 mm) less than the plate thickness, t, which is sufficient to ensure that the edge remains. See Figure C-J2.1(b).

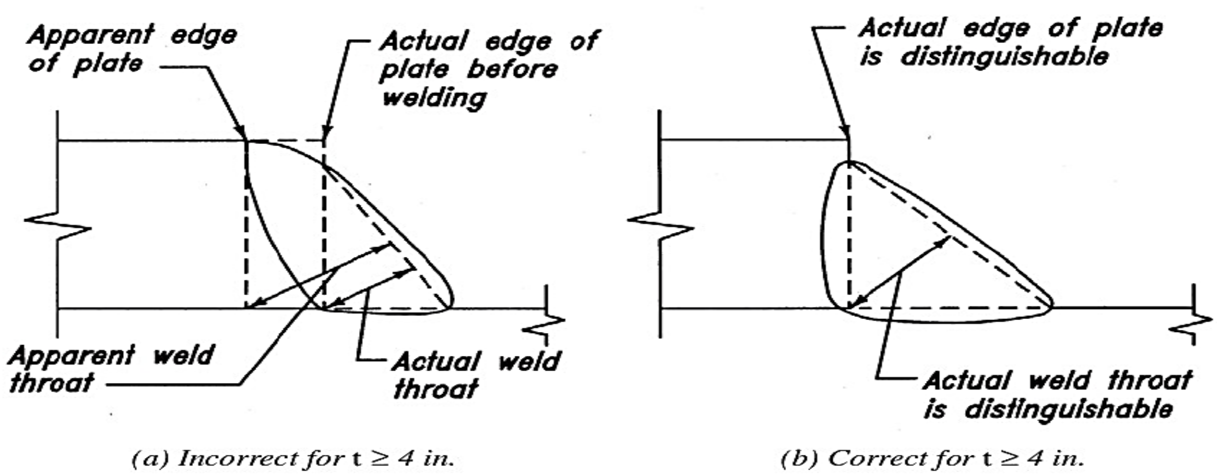
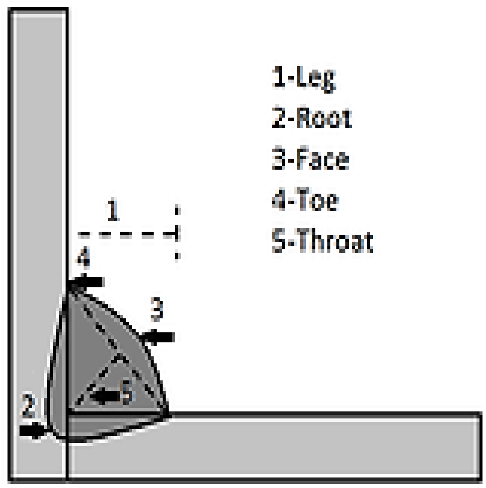


Fig. C-J2.1. Identification of plate edge.



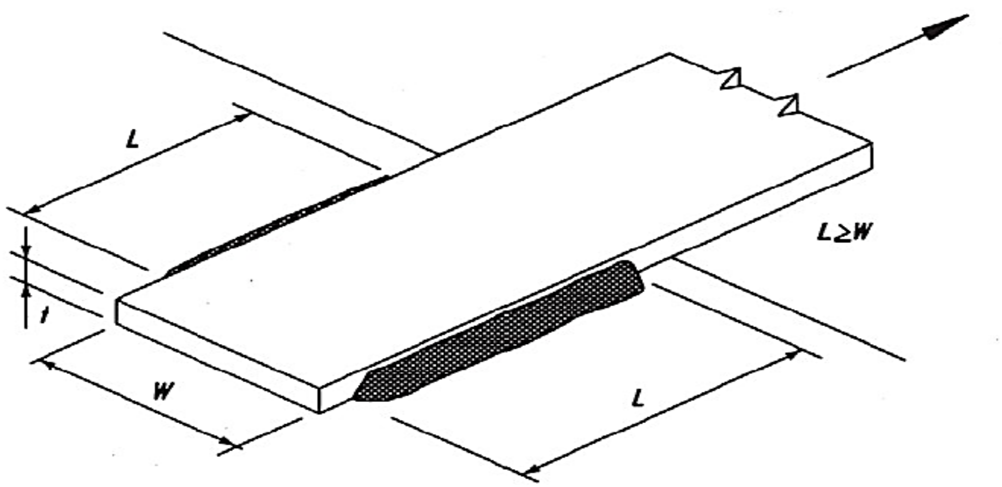


Fig. C-J2.2. Longitudinal fillet welds.

Limitations on weld dimensions (See AISC Spec. **J2.2b** on page **16.1-54** of manual)

Minimum size (a_{min})

Some references a is **D**

(Mean size of fillet weld)

- function of the thickness of the thickest connected plate
- **given in Table J2.4 of the AISC specifications**

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TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thinner Part Joined, in. (mm)	Minimum Size of Fillet Weld,[a] in. (mm)
To 1/4 (6) inclusive	1/8 (3)
Over 1/4 (6) to 1/2 (13)	3/16 (5)
Over 1/2 (13) to 3/4 (19)	1/4 (6)
Over 3/4 (19)	5/16 (8)

[a] Leg dimension of fillet welds. Single pass welds must be used.
Note: See Section J2.2b for maximum size of fillet welds.

Maximum size (a_{max})

- function of the thickness of the thinnest **connected plate**:

-for plates with thickness < 0.25 in.$\Rightarrow a_{max} = 0.25$ in.

-for plates with thickness ≥ 0.25 in.$\Rightarrow a_{max} = t - \frac{1}{16}$ in.

Minimum length welding (l)

- length (l) $\geq 4a$ otherwise, $a_{eff} = l / 4$

  - Read **J2.2 b**
  - Intermittent fillet welds: $l_{min} = 4a$ **or** 1.5 in. (greater).

Maximum effective length (l)

-If weld length $l/a \leq 100$, then effective weld length (l_{eff}) = l

- If $l/a > 100$
- If $l/a > 300$

read AISC J2.2b

$l \geq W$, W is the transverse distance between welding

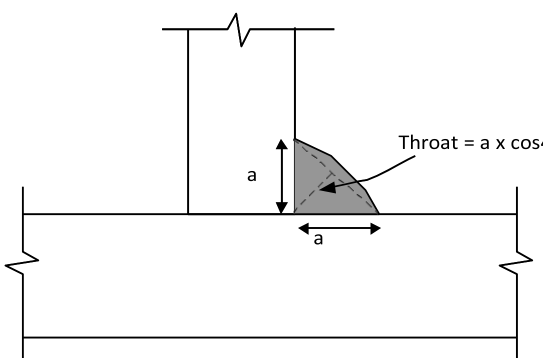
Weld Terminations - read AISC J2.2b

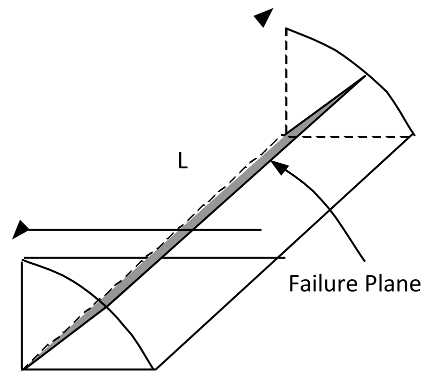
- Lap joint – fillet welds terminate at a distance > *a* from edge**.**

-Weld returns around corners must be ≥ 2 a

Design of Welded Connections

- Fillet welds are most common and used in all structures.
- Weld sizes are specified in 1/16 in. increments
- A fillet weld can be loaded in any direction in shear, compression, or tension. However, it always ***fails in shear***.
- The shear failure of the fillet weld occurs along a plane through the throat of the weld, as shown in the Figure below.





- Shear stress in fillet weld of length L subjected to load P : $f_v = \dfrac{P}{0.707\, a\, L_w}$

- ***In this stage will be study the tension load.***

Sometimes D

Strength of the weld:

If the ultimate shear strength of the weld (f_w)⇒	$R_n = f_W \times 0.707 \times a \times L_W \times \beta$
LRFD	**ASD**
ϕR_n, where ϕ factor = 0.75	Rn/Ω, where Ω factor =2.0

ϕ *and* Ω if tension or compression parallel to weld axis otherwise in Table J2.5.

- f_w = shear strength of the weld metal is a function of the electrode used in the **SMAW** process.
  The tensile strength of the weld electrode can be **60, 70, 80, 90, 100, 110, or 120 ksi.**

The corresponding electrodes are specified using the nomenclature **E60XX, E70XX, E80XX, and so on.** This is the standard terminology for weld electrodes.

- The strength of the electrode should match the strength of the ***base metal***.

If yield stress (σ_y) of the base metal is ≤ **60 - 65 ksi**, use E70XX electrode.

- If yield stress (σ_y) of the base metal is > **60 - 65 ksi**, use E80XX electrode.

- E70XX is the most popular electrode used for fillet welds made by the SMAW method.
- **Table J2.5** in the AISC Specifications gives the weld design strength

$$f_w = 0.60\, F_{EXX}$$

Example: For E70XX, $f_w = 0.60 \times 70 = 42$ ksi

β depended on the Maximum effective length - read AISC J2.2b

- If l /a $\leq 100 \Rightarrow \beta = 1.0$
- If l /a $> 100 \Rightarrow \beta = 1.2 - 0.002(\frac{l}{a}) \leq 1.0$
- If l /a $\geq 300 \Rightarrow \beta = 0.6$

*Note: **l** is the length of welding is parallel to the load direction (one side)*

Strength of the base metal in shear:

Additionally, (for LRFD and ASD)the shear strength of the base metal must also be considered:

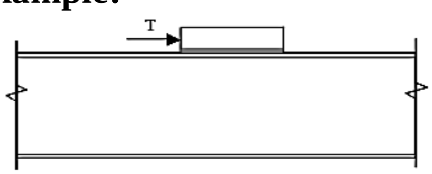
$$\phi R_n = 0.9 \times 0.6\, F_y \times t \times Lw \text{ (LRFD)}$$

$$\frac{R_n}{\Omega} = \frac{0.6\, Fy \times t \times Lw}{1.67} \quad (ASD)$$

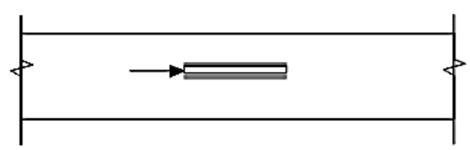
Where $t \times Lw$ =Area of base metal subjected to shear

Where: $\boldsymbol{F_y}$ is the yield strength of the base metal, $\boldsymbol{t}$ is the shorter distance from the root of the joint to the face of the weld.

- **For example:**



Elevation



Plan

Strength of weld in shear

$= 0.75 \times 0.707 \times a \times L_w \times f_w$

$$\frac{0.707 \times a \times Lw \times fw}{2}$$

Strength of base metal

$= 0.9 \times 0.6\, F_y \times t \times L_w$ (LRFD)

$$= \frac{0.6\, Fy \times t \times Lw}{1.67} (ASD)$$

Smaller governs the strength of the weld

- Always check weld metal and base metal strength. Smaller value governs. In most cases, the weld metal strength will govern.
- In weld design problems; it is advantageous to work with strength per unit length of the weld or base metal.

Note: L_w *is represent the summation lengths of welding except end return.*

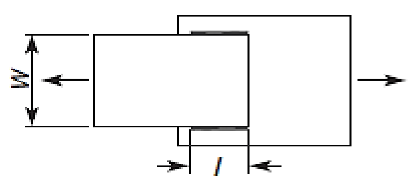
Tension strength of the member:

LRFD	ASD
Gross-sectional yielding: $\Phi R_n = \Phi\, A_g\, F_y$ $\Phi = 0.9$	**Gross-sectional yielding:** $\frac{R_n}{\Omega} = \frac{A_g\, F_y}{\Omega}$ $\Omega = 1.67$
Tensile-rupture strength: $\Phi R_n = \Phi\, A_e\, F_u$ Where $A_e = UA_g$ $\Phi = 0.75$	**Tensile-rupture strength:** $\frac{R_n}{\Omega} = \frac{A_e\, F_u}{\Omega}$ $\Omega = 2$ Where $A_e = UA_n$

Value of Reduction Factor (*U*) respect to connection (welding)

Plates where the tension load is transmitted by longitudinal welds only, as shown in Figure below.

$$\left.\begin{array}{l} U = 1.0 \ \text{ when } \ l \geq 2w \\ U = 0.87 \ \text{ when } \ 2w > l \geq 1.5w \\ U = 0.75 \ \text{ when } \ 1.5w > l \geq w \end{array}\right\} \text{For plates and bars}$$

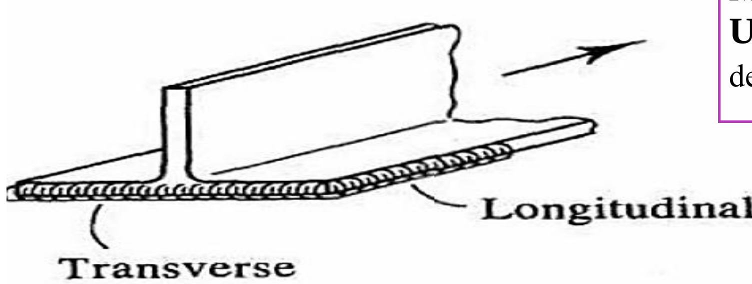


Some shapes welded in transverse direction besides the longitudinal direction, the reduction factor become:

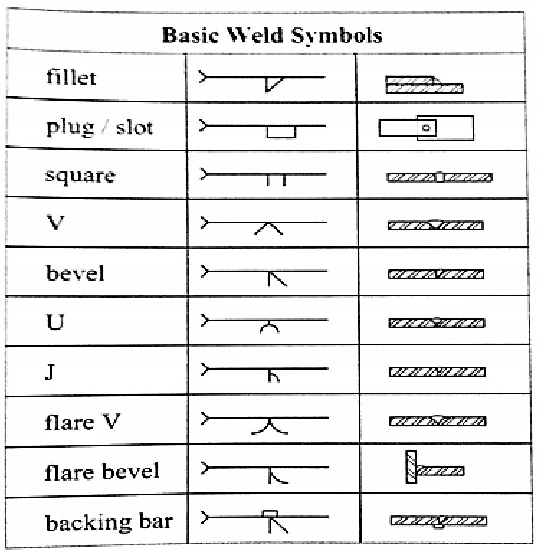
$U = 1 - \frac{\bar{x}}{l} \leq 0.9$ **(check)**, where l is the larger length of connection, as shown in figure below. Also, the $A_n = A_g$.

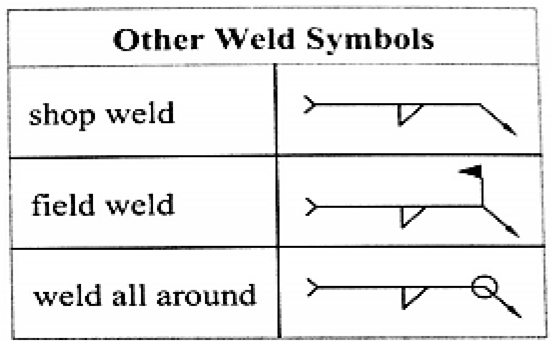
$$A_e = UA_g$$

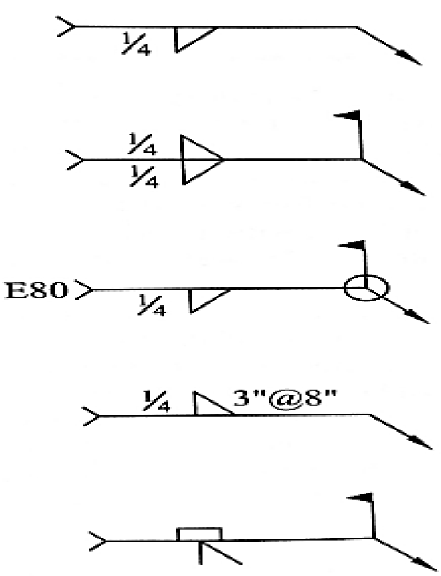
May be assume U=1.0
depend on AISCM D3.1



Note: End return at the edge corner ≥2a , figure below shows E70XX







a. ¼" fillet weld, shop welded on near side

b. ¼" fillet weld, field welded on both sides

c. ¼" fillet weld, field weld all around, use E80 electrodes

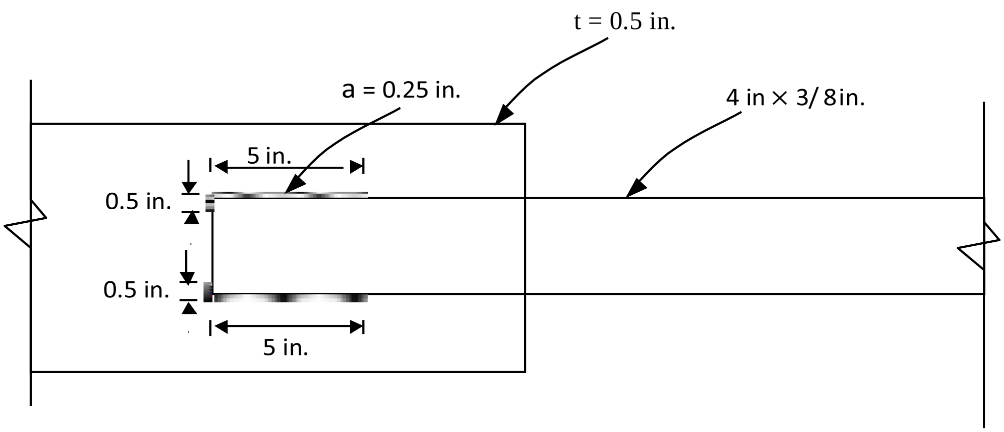
d. ¼" fillet weld, shop welded on far side, 3"-long welds at 8" on center

e. single bevel weld, field welded with backing bar

TABLE J2.5
Available Strength of Welded Joints, kips (N)

Load Type and Direction Relative to Weld Axis	Pertinent Metal	ϕ and Ω	Nominal Strength (F_{BM} or F_w) kips (N)	Effective Area (A_{BM} or A_w) in.^{2} (mm^2)	Required Filler Metal Strength Level[a][b]
COMPLETE-JOINT-PENETRATION GROOVE WELDS					
Tension Normal to weld axis	Strength of the joint is controlled by the base metal				Matching filler metal shall be used. For T and corner joints with backing left in place, notch tough filler metal is required. See Section J2.6.
Compression Normal to weld axis	Strength of the joint is controlled by the base metal				Filler metal with a strength level equal to or one strength level less than matching filler metal is permitted.
Tension or Compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.				Filler metal with a strength level equal to or less than matching filler metal is permitted.
Shear	Strength of the joint is controlled by the base metal				Matching filler metal shall be used.[c]
PARTIAL-JOINT-PENETRATION GROOVE WELDS INCLUDING FLARE VEE GROOVE AND FLARE BEVEL GROOVE WELDS					
Tension Normal to weld axis	Base	$\phi = 0.90$ $\Omega = 1.67$	F_y	See J4	Filler metal with a strength level equal to or less than matching filler metal is permitted.
	Weld	$\phi = 0.80$ $\Omega = 1.88$	$0.60 F_{EXX}$	See J2.1a	
Compression Column to Base Plate and column splices designed per J1.4(a)	Compressive stress need not be considered in design of welds joining the parts.				
Compression Connections of members designed to bear other than columns as described in J1.4(b)	Base	$\phi = 0.90$ $\Omega = 1.67$	F_y	See J4	
	Weld	$\phi = 0.80$ $\Omega = 1.88$	$0.60 F_{EXX}$	See J2.1a	
Compression Connections not finished-to-bear	Base	$\phi = 0.90$ $\Omega = 1.67$	F_y	See J4	
	Weld	$\phi = 0.80$ $\Omega = 1.88$	$0.90 F_{EXX}$	See J2.1a	
Tension or Compression Parallel to weld axis	Tension or compression in parts joined parallel to a weld need not be considered in design of welds joining the parts.				
Shear	Base	Governed by J4			
	Weld	$\phi = 0.75$ $\Omega = 2.00$	$0.60 F_{EXX}$	See J2.1a	

Example 1/ Determine the design strength of the tension member and connection system shown below. The tension member is a 4 in. × 3/8 in of A572 Gr.50. thick rectangular bar. It is welded to a 1/2 in. thick gusset plate using E70XX electrode. Consider the yielding and fracture of the tension member. Consider the shear strength of the weld metal and the surrounding base metal.



<u>Solution:</u>

1. **Specification and dimensions:**

Steel	F_y	F_u	F_{EXX}	*Sec.1*	*Sec.2*
A572 Gr.50	50	65	70	PL 4 in × 3/ 8 in	PL 0.5 in.

2. Check for the limitations on the weld geometry:

t_{member} = 3/8 in.=0.375 in.

t_{gusset} = 0.5 in.

⇒Thinner part =3/8 in.

⇒ a_{min} = 3/16 in. (from **Table J2.4)**

- for thickness = 0.375 in. ≥ 0.25 in.⇒ $a_{max} = t - \frac{1}{16}$ in.

⇒ a_{max} = 3/8 - 1/16 = 5/16 in.

Fillet weld size used = *a* = 1/4 in. OK.

- l_{min} = 1.0 in.= (4 a) OK.

l_{min} for each length of the weld = 5 in.> *W* (*transverse distance between welds*, see **J2.2b**)

Given length = 5.0 in., which is > l_{min}. OK.

End returns at the edge corner size - minimum = 2 a = 2(1/4)= 0.5 in. OK.
l /a = 5/0.25= 20 $\leq$100 $\Rightarrow \beta = 1.0$

3. Design strength of the weld and base metal:

$R_n = f_W \times 0.707 \times a \times L_W = 0.6\ F_{EXX} \times 0.707 \times a \times L_W \times \beta$ $= 0.6 \times 70 \times 0.707 \times 0.25 \times 10 \times 1.0 = 74.24$ kips	
LRFD	**ASD**
$\phi R_n = 0.75 \times 74.24 = 55.67$ kips	$Rn/\Omega = \frac{74.24}{2} = 37.12\ kips$
Base Metal strength = $0.9 \times 0.6\ F_y \times t \times L_w$ = 0.9 × 0.6 × 50 × 3/8 × 10= 101.25 *kips*	Base Metal strength $= \frac{0.6\ Fy \times t \times L_w}{1.67}$ $= \frac{0.6 \times 50 \times 3/8 \times 10}{1.67} = 67.4\ kips$

4. Tension strength of the member:

LRFD	ASD
Yielding $\Phi R_n = \Phi\ A_g\ F_y = 0.9 \times 4 \times \frac{3}{8} \times 50 = 67.5\ kips$ Rupture ***U=0.75 (due to 1.5w > l ≥w)*** $A_e = UA_g = 0.75 \times 4 \times \frac{3}{8} = 1.125$ in^2 $\Phi R_n = \Phi\ A_e\ F_u = 0.75 \times 1.125 \times 65 = 54.84\ kips$ *The design strength of the member-connection system = 54.84 kips. Tension fracture of the member governs. The end returns at the corners were not included in the calculations.* (Smaller value)	Yielding $\frac{P_n}{\Omega} = \frac{A_g\ F_y}{\Omega} = \frac{4 \times \frac{3}{8} \times 50}{1.67} = 44.9\ kips$ **U and A_e as LRFD design** Rupture $\frac{P_n}{\Omega} = \frac{A_e\ F_u}{\Omega} = \frac{1.125 \times 65}{2} = 36.56\ kips$ *The design strength of the member-connection system = 36.56 kips. Tension fracture of the member governs. The end returns at the corners were not included in the calculations.* (Smaller value)